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Dynamic Call Admission Control and Resource Reservation with Interference Guard Margin (IGM) for CDMA Systems

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Abstract— **A dynamic call admission control and resource reservation scheme suitable for CDMA system is proposed. Preferential treatment is given to high priority calls by pre-reserving an interference guard margin (IGM), which is dynamically adjusted by referencing traffic conditions in neighboring cells based upon users' quality of service. A comprehensive service model is used including users' service rates, priority levels, mobility and rate adaptivity. Simulations are conducted by OPNET to study the performance in terms of the objective function under different traffic conditions.**

I. Introduction

The Radio Resource Management (RRM) module in the cellular network system is responsible for the utilization of air interface resources. RRM is needed to offer efficient system utilization and guarantee a certain QoS level to different mobile users according to their traffic profiles and QoS requirements. The call admission control (CAC) mechanism is one of the most important components of RRM affecting the resource management efficiency and QoS guarantees provided to users. The radio resource reservation estimation (RRE) mechanism helps CAC to decide how much resource is needed to be reserved in order to provide QoS guarantees to mobile users. The RRE module residing in each base station dynamically estimates the amount of resource to be reserved by referencing traffic conditions in neighboring cells periodically or upon the call request arrival depending on the design of the system.

In 2G TDMA/FDMA wireless systems, network accessibility, which is controlled by the radio resource management (RRM) module, is typically designed based on the number of available channel elements. Due to limited system resources (in terms of the number of channels), preferential treatment should be given to high priority calls to support them with higher QoS guarantees when the system is congested. An ongoing handoff call is considered to hold higher priority than a new call request. It is a widely agreed upon policy because of human nature, wherein people expect to receive services continuously once they are admitted into the system. Therefore, dropping an ongoing call during handoff is less tolerable than blocking a new call. One way to provide preferential treatment is to pre-reserve a certain number of channels for high priority calls such as handoff calls. This is referred to as the guard channel (GC) scheme [1]. Various GC schemes have been widely studied as discussed in Section II [1–4].

However, the GC approach is not applicable in code division multiple access (CDMA) systems. The channel capacity is limited by maximum tolerable interference in a CDMA system, while the channel capacity in a conventional TDMA/FDMA system is limited by available channels. A new call request in CDMA systems is admitted if it does not introduce excessive interference into the system. Knutsson *et al.* [5] investigated the CAC for downlink. Due to the asmmyetric traffic conditions in the reverse (from the mobile to the base-station) and the forward link (from the base-station to the mobile), the CAC scheme should admit a call only when the call admission requirement are met in both directions. However, reserve link capacity is considered more constrained in CDMA system as in [6, 7].

Liu and Zarki [6] proposed an SIR-based CAC scheme. The authors assumed that the base station receives the same signal power from each of its mobile users and CAC was designed based on the variation of signal to interference ratio (SIR) value. However, such an assumption is not valid in a practical system due to the use of power control, which adjusts the signal power level for each mobile user according to the link condition. Consequently, the use of power control keeps the SIR to its target value during the whole operation as described in [8]. Shin *et al.* [7] proposed an interference-based channel assignment scheme for DS-CDMA Cellular Systems. However, their CAC algorithm was based on fixed resource reservation, where a fixed number of channels is reserved to give the preferential treatment to high priority handoff calls.

In this paper, we present a dynamic resource management scheme for heterogeneous traffic. System resources are allocated efficiently by implementing dynamic resource reservation estimation (RRE) and rate-adaptive CAC schemes. In our scheme, a constant target SIR value is assumed due to the use of power control in the real system. Here, the total interference level in the system is computed by employing the load curve introduced by Holma and Laakso [9]. The use of load curve also makes it possible to handle different levels of interference-increase introduced by heterogeneous traffic with various service rates.

The main features of our proposed scheme are summarized as follows. First, it supports rate adaptive characteristics for multiple services with flexible QoS guarantees. Second, it takes heterogeneous traffic mobilities into consideration to achieve better resource estimation. Third, by using adaptive resource reservation estimation (RRE), the amount of reserved resource can be dynamically changed by referencing the traffic condition in neighboring cells. Fourth, the proposed scheme bridges two principle concepts, the guard channel (GC) and the load curve (LC), to enable the preferential treatment for spread spectrum system.

The remaining parts of this paper are organized as follows. In Section II, the GC concept and the loading curve will be reviewed. We then present the interference guard margin (IGM) scheme in Section III to provide preferential treatment to mobile users for CDMA systems. QoS metrics are measured in terms of the objective function, the handoff dropping probability and the new call blocking probability. Section IV shows some simulation results conducted with OPNET by using a comprehensive service model. Finally, concluding remarks and future work are presented in Section V.

II. Related Work

A. Preferential Treatment in Channel-based Systems

The use of guard channel (GC) in FDMA/TMDA system is a good scheme to provide preferential treatment to different priority calls. The basic GC scheme [1] can be extended to deal with multimedia traffics with different priorities [2], in which multiple thresholds are used. The QoS metrics for the performance is often measured by an objective function $J = P_n + \omega \cdot P_h$. In which, P_n and P_h are new call blocking and handoff dropping probabilities, respectively. Penalty weighting, $\omega = 10$, is given to reflect the higher cost for dropping a handoff call. Fixed GC scheme cannot adaptive to the quick variation of the traffic pattern. Recently, dynamic GC schemes have been discussed in the literature to improve the system efficiency while providing the QoS guarantees to priority calls. These dynamic schemes adaptively reserve resources needed for priority calls and, therefore, accept more lower priority calls as compared to a fixed GC scheme. Acampora and Naghshineh [3] applied a linear weighting scheme as part of their admission control algorithm. The linear weighting scheme uses the average number of ongoing calls in all cells within the region of awareness to determine the admission policy. Sutivong and Peha [4] adopted a hybrid scheme based on the weighted sum of ongoing calls in the originating cell and in other cells to determine the admission scheme. Dynamic GC schemes are generally very complicated. Since their performance cannot be easily analyzed with analytical models, they are often verified via computer simulation.

B. Capacity and Load Estimation in CDMA Systems

The measurement of the resource capacity in a spread spectrum system is very different from that in conventional TDMA/FDMA systems. In conventional TDMA and FDMA systems such as IS-54 (TDMA adopted in North American) and GSM (hybrid TDMA/FDMA adopted in Europe), the number of traffic channels is fixed. It is determined by the number of time slots in the TDMA system or by the number of non-overlapping frequencies in the FDMA system [**?**]. In such systems, traffic channels are allocated to users as long as there are available channels. Otherwise, the call is blocked.

The capacity of a CDMA system is limited by the total interference the system can tolerate. Such a system is referred to as the interference-limit system. Each additional active mobile user will increase the overall level of interference in the system. The interference level increases rapidly when the system load reaches a certain level. The total number of users a system can accommodate depends on users' traffic profiles. Users with different traffic profiles and attributes such as data rates, the signal-to-Interference ratio (SIR) requirement, media activity, introduce different amount of interference to the system. These factors are especially important in 3G wireless networks that support multimedia and multiple services.

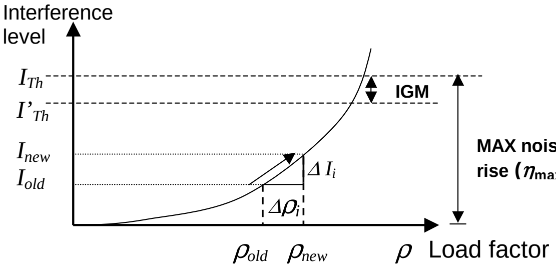


Fig. 1. The load curve and the load estimation increase w.r.t active user's activities.

The capacity of a cellular system not only depends on the total bandwidth allocated to the system, but also the total interference introduced by active mobile users. Liu [6], Holma [9], and Viterbi [10] studied the effect of interference increase for traffic.

Let ϵ_i denote target SIR for user i, which can also be expressed as the ratio of $(E_b/N_0)_i$. Then, we have

$$\epsilon_i \equiv (E_b/N_0)_i = \frac{W}{\nu_i R_i} \cdot \frac{S_i}{I_{total} - S_i}, \tag{1}$$

where E_b is the energy per user bit and N_0 the noise spectral density, W is the chip rate of W-CDMA system, R_i is the source rate in bits, S_i is the received power at the base station from user i, ν_i is the activity level of user i, and I_{total} is the total received power at the base station. I_{total} is limited by an upper-bound for a system. When I_{total} is higher than the upper-bound, the system is unstable and the overall interference increase dramatically. We can express the received power S_i for user i at the base station as

$$S_i = (1 + \frac{W}{\epsilon_i \cdot \nu_i \cdot R_i})^{-1} \cdot I_{total} = \triangle\rho_i \cdot I_{total}, \tag{2}$$

where $\triangle\rho_i \equiv (1 + \frac{W}{\epsilon_i \cdot \nu_i \cdot R_i})^{-1}$ is called the load factor increment [9]. The current load factor of such an interference system is the sum of load factor increments brought by N active mobile users, i.e., $\rho = \sum_{i=1}^{N} \triangle\rho_i$. Shapira and Padovani [11] and Holma *et al.* [**?**, 9] estimated the interference increase by taking into account the load curve as shown in Fig. 1. The ratio of I_{total} to the background noise P_N is called noise-rise and denoted by η. The maximum value of η, denoted as η_{max}, is normally set to 10 [10]. The noise-rise, η, in Fig. 1 can be written as

$$\eta \equiv \frac{I_{total}}{P_N} = \frac{\sum_{i=1}^{N} S_i + P_N}{P_N} = (1-\rho)^{-1} = (1 - \sum_{i=1}^{N} \triangle\rho_i)^{-1}. \tag{3}$$

By taking the partial derivative of I_{total} with respective to ρ_i, it yields that $\triangle I_i / \triangle\rho_i \equiv \partial I_{total}/\partial\rho_i = \partial(P_N/(1 - \rho))/\partial\rho_i$. Thus, we can get the interference increment as

$$\triangle I_i = \frac{\triangle\rho_i}{1-\rho} \cdot I_{total}. \tag{4}$$

The load curve serves as a good tool for interference increment estimation in our proposed model.

III. Proposed Schemes

In this section, we will develop a dynamic call admission control scheme based on two concepts, the guard channel developed in the TDMA/FDMA system and the load factor for system capacity estimation. The proposed scheme modifies and bridges these two concepts into one to be applicable to CDMA systems. First, a certain amount of interference guard margin (IGM), instead of guard channels, is pre-reserved for high priority calls. The amount of IGM is dynamically adjusted by the resource reservation estimation module. Second, the load curve is used to estimate the load increase as well as the interference increase.

A. Service Model and Preferential Treatment with IGM

In a mobile communication system with N active mobile users, the ith ($i < N$) user's traffic profile, which characterizes its services, is described as

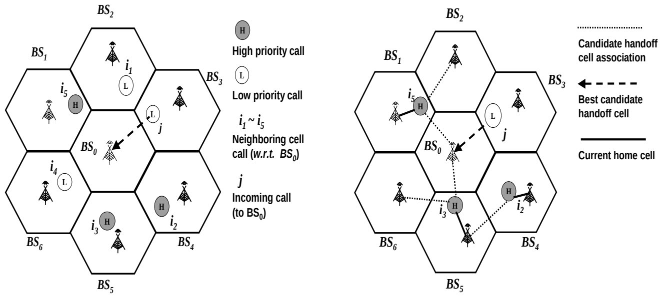
$$\Im(i) = \{r_i, (R_{max}, R_{min})_i, \Pi_i, M_i\}, \qquad (5)$$

where r_i, $(R_{max}, R_{min})_i$, Π_i and M_i in $\Im(i)$, denote user i's rate adaptivity, service rate range, priority and mobility, respectively. r_i is a binary indicator which describes whether it can be serviced in the degraded mode when the system is congested. The service rate range describes the target bandwidth consumption. The priority tag helps the system to identify high priority users, who are likely to receive better QoS guarantee with a better quality mode. Three mobility types are considered in our service model (high, moderate and low mobility). Each different mobility traffic has a different weighting factor in estimating the amount of resource necessary to be reserved. This is discussed in our proposed resource reservation estimator in Section III-B.

The concept of the interference guard margin is illustrated in Fig. 1. For a new call to be admitted, the total interference level should not exceed the upper bound of the interference with threshold I_{th} that the system can tolerate. In addition to the constraint of I_{th}, a lower priority call should comply with the augmented constraint I'_{th}. The margin between I_{th} and I'_{th} is exactly the guard margin, which provides the preferential treatment to high priority calls by limiting the access to the low priority calls.

B. Dynamic Resource Reservation Estimator and Call Admission Control

When a mobile terminal (MT) moves toward cell boundaries, the neighboring base stations (BS) receive stronger signal from it. Each of the BS in the neighboring cells sends messages to mobile switching center (MSC) to register itself as a handoff candidate for MT. This bookkeeping process is done in MSC by using a handoff candidate registration (HCR) table to maintain the registration record and to inform that MT about where to handoff when its signal fades. This table provides useful information to find out a smaller set of calls of interested. They are used to estimate the amount of resource, in terms of interference margin, needed to be reserved when admitting a low priority calls. In other words, before admitting a new or handoff call, j, into a cell, RRE estimates the interference guard margin (IGM) dynamically based on the weighted sum of estimated potential interference-increments.



(a) (b)

Fig. 2. Set $S(j)$ in resource-reservation estimation: (a) $\Pi(i) > \Pi(j)$ and (b)$\Lambda(j)^* \in \Lambda(i)$.

$$\begin{aligned} IGM &= \sum_{i \in S} \omega_i \cdot \triangle I_{min,i} = \sum_{i \in S} \omega_i \cdot (\frac{\triangle \rho_i}{1-\rho}) \cdot I_{total} \\ &= \sum_{i \in S} \omega_i \cdot \frac{(1 + \frac{W}{\epsilon_i \cdot \nu_i \cdot R_{min,i}})^{-1}}{1-\rho} \cdot I_{total} \end{aligned} \qquad (6)$$

In Eq. (6), the weighting factor, ω_i, for each call is a function of the mobility of user i, M_i, and the distance from user i to base station, d_i. The value of the weighting factor, ω_i, is proportional to the ratio of mobility to distance for user i, i.e. $\omega_i \propto (M_i/d_i) \equiv T_i^{-1}$. We reserve the resource according to the weighting factor which implies a high speed mobile user is more likely to handoff into the current cell when it is farther from a low speed mobile user. Thus, we have

$$\omega_i = \begin{cases} T_{Th}/T_i & \text{if } T_i > T_{Th} \\ 1 & \text{if } T_i < T_{Th} \end{cases} \qquad (7)$$

The amount of IGM, defined in Eq. (6), represents the resource needed to be reserved for priority calls in our proposed CAC algorithm. Let us define a set, $S(j)$, for call j that need to be considered for the estimation of resource reservation. $S(j)$ consists of all neighboring active calls that satisfy two criteria. First, the handoff candidate cell of call i in HCR table is the same as the target cell of call j. Second, the priority of call i is higher than that of incoming call j. Note that, there is one more hidden assumption. That is, the current cell of neighboring call i is not equal to the target cell of incoming call j.

We define three operations on call i. (1) $\Pi(i)$ returns the priority of call i, (2) $\Lambda(i)$ lists all the handoff candidate cell of call i, and (3) $\Lambda^*(i)$ marks the best candidate target cell of call i. Therefore, set $S(j)$ can be represented as in Eq.(8).

$$S(j) = \{i | \Pi(i) > \Pi(j), \Lambda(i) = \Lambda^*(j)\} \qquad (8)$$

In other words, set $S(j)$ consists of calls from the neighboring cells, whose (1) handoff candidate cell of call i in the HCR table is the same as the target cell of call j and (2) the priority of call i is higher than that of call j. The proposed CAC algorithm for the new and handoff call request can be expressed as the pseudo codes as in Fig. 3.

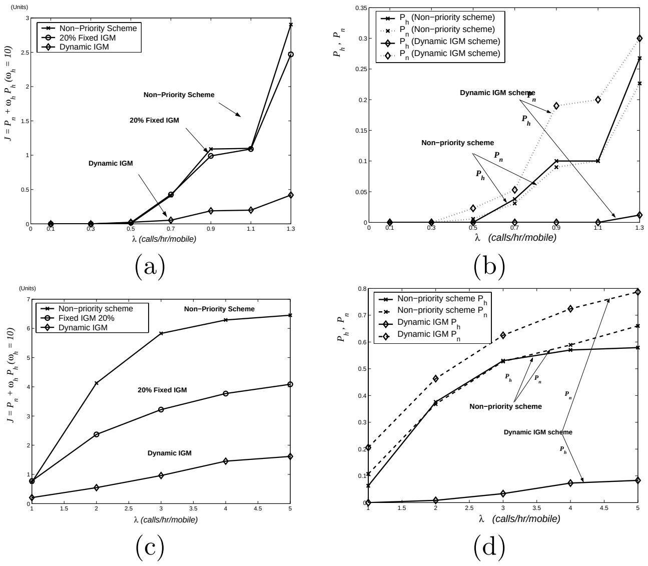
```
If Incoming calls are new calls
  If Calls are non-rate adaptive
    If $(I_{current} + \triangle I_i) < (I_{Th} - IGM_{new})$
      Admit call request with rate $R_i$
    Else
      Reject call request
  Else /*Calls are rate adaptive*/
    If $(I_{current} + \triangle I_{max,i}) < (I_{Th} - IGM_{new})$
      Admit call request with rate $R_{max,i}$
    Else If$(I_{current} + \triangle I_{half,i}) < (I_{Th} - IGM_{new})$
      Admit call request with rate $R_{half,i}$
    Else If$(I_{current} + \triangle I_{min,i}) < (I_{Th} - IGM_{new})$
      Admit call request with rate $R_{min,i}$
    Else
      Reject call request
Else /*Incoming calls are handoff calls*/
  If Calls are non-rate adaptive
    If $(I_{current} + \triangle I_i) < (I_{Th} - IGM_{hoff})$
      Admit call request with rate $R_i$
    Else
      Reject call request
  Else /*Calls are rate adaptive*/
    If $(I_{current} + \triangle I_{max,i}) < (I_{Th} - IGM_{hoff})$
      Admit call request with rate $R_{max,i}$
    Else If$(I_{current} + \triangle I_{half,i}) < (I_{Th} - IGM_{hoff})$
      Admit call request with rate $R_{half,i}$
    Else If$(I_{current} + \triangle I_{min,i}) < (I_{Th} - IGM_{hoff})$
      Admit call request with rate $R_{min,i}$
    Else
      Reject call request
```

Fig. 3. The proposed call admission control algorithm.

IV. Simulation Results

A. System and Service Model Parameters

Simulations were conducted by using the OPtimized Network Engineering Tool (OPNET) [12]. A network topology with 7 cells, which covers a region in a non-overlapped fashion, is applied. Each cell has its own base station. The maximum interference level I_{th} is normally set to ten times of background noise, i.e. $\eta_{max} = 10$. There are 420 mobile terminals with three types of mobility (three mobilities are equally distributed). MSC is connected with each base station via a wired link. There are a number of mobile users with their own traffic profiles in each cell, which can move across two or more cells according to their predetermined trajectories. Along its trajectory, a mobile user can originate connection requests randomly at its call generation rate. A Poisson call arrivals and exponentially distributed call holding time are assumed. Call arrival and call holding time are controlled by two parameters. (1) λ: the mean request arrival rate measured in the number of connections per hour. (2) l: the mean call holding time of each flow in minutes, which is set to the value of 15 minutes for each call connection. This assumption is reasonable when considering multimedia and web applications supported in third generation system. Increasing the value of λ results in the increment of the network traffic load. Values used in traffic profile, $\Im(i)$, are listed as follows:(1) $r_i \in \{YES, NO\}$. (2) $R_{max,i}$ set to 19.2 Kbps, 38.4 Kbps and 76.8 Kbps are applied for voice, audio and video transmissions, respectively. $R_{min,i}$ is set to be half or smaller fraction of $R_{max,i}$ (3) $\Pi \in \{new, handoff\}$ (4) $M_i \in \{HIGH, MOD, LOW\}$.



(a) (b)

(c) (d)

Fig. 4. Performance comparison for non-rate adaptive users under different traffic densities: (a) objective function J for light to moderate traffic, (b) new call blocking rate P_n and the handoff dropping rate P_h for light to moderate traffic, (c) objective function J for heavy traffic, and (d) new call blocking rate P_n and the handoff dropping rate P_h for heavy traffic.

Without loss of generality, system parameters used in simulation are W-CDMA chip rate, $W = 3.84Mcps$, Media activity, $\nu = 1$, and Target SIR, $\varepsilon_i = 7dB$. The QoS performance are measured in terms of the objective function, $J = P_n + \omega \cdot P_h$, as defined in Section II. Our goal is to minimize this objective (penalty) function value. The performance of the proposed dynamic IGM scheme is compared with the results using non-priority (complete sharing) scheme and fixed guard margin scheme.

B. Simulation Results for Non-rate Adaptive Traffic

Figs. 4(a) and (b) are evaluated under light to moderate traffic load with λ varying from 0.1 to 1.5 (calls per hour per user). Fig. 4(a) shows that the dynamic IGM scheme has the best QoS performance in terms of the objective function with a smaller value. Fig.4 (b) gives the comparison between the proposed dynamic IGM scheme and the non-priority (complete sharing) scheme. The results indicate that the new call user and the handoff user in the non-priority scheme experience a similar high dropping rate since no preference treatment is provided. However, the dynamic IGM scheme significantly reduces the handoff dropping probability, P_h, without much increase in the new call blocking probability, P_n, as compared to the non-priority scheme.

Figs. 4(c) and (d) are evaluated under moderate to heavy traffic load (λ varying from 1 to 5) for the objective function and its associated call dropping rates, respectively. Similarly, the non-priority scheme cannot provide preferential treatment to the new call user and the handoff user and experience a similar high dropping rate. The proposed IGM scheme provides a solution to this problem.

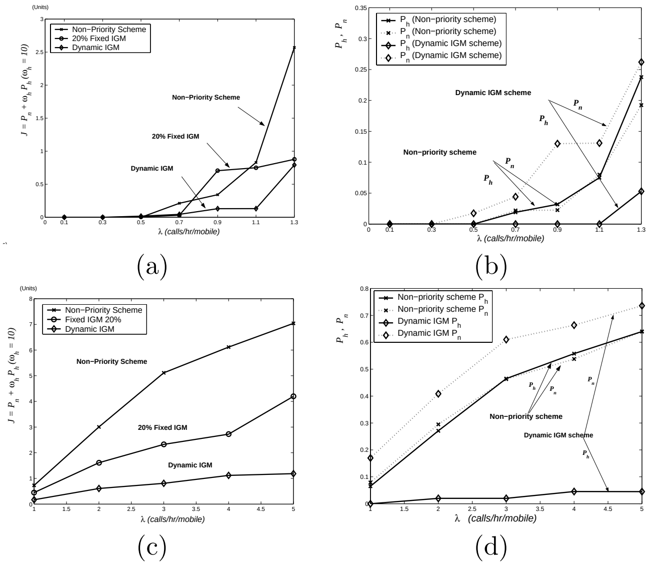


Fig. 5. Performance comparison for rate adaptive users under different traffic densities: (a) objective function J under light to moderate traffic, (b) new call blocking rate P_n and the handoff dropping rate P_h under light to moderate traffic, (c) objective function J under heavy traffic, and (d) new call blocking rate P_n and handoff dropping rate P_h under heavy traffic.

C. Simulation Results for Rate Adaptive Traffic

In the presence of rate adaptive traffic, users can be admitted into a system with degraded service (with lower service rate) when the system is congested. Figs. 5(a) and (b) are evaluated under light to moderate traffic load with λ varies from 0.1 to 1.5. The performance comparison in terms of the objective function (J) is given in Fig. 5(a). Results indicate that, in light traffic condition ($\lambda = 0.1$ to 1.1), the non-priority scheme (complete sharing scheme) is better than the fixed scheme. This is because the fixed scheme cannot adapt to traffic condition and reserves excessive resource in light traffic condition, which leads to higher call dropping rates. However, the proposed dynamic IGM scheme can adapt to each traffic condition and thus have a better QoS performance. Fig. 5(b) provides the comparison of preferential treatment between the proposed dynamic IGM scheme and the non-priority (complete sharing) scheme. The proposed dynamic IGM scheme has a better preferential treatment capability under light as well as moderate traffic loads.

Fig.5 (c) is evaluated under moderate to heavy traffic load with λ varies from 1 to 5 (calls per hour per user) for the objective function. The proposed dynamic IGM scheme has a better QoS performance under moderate as well as heavy traffic loads. The associated call dropping rates are shown in Fig. 5(d). Results show that the proposed dynamic scheme significantly reduce the handoff dropping probability without increasing the new call blocking probability significantly.

V. CONCLUSION

A fixed and a dynamic call admission control scheme, and their associated resource reservation schemes, based on the concept of interference guard margin (IGM) for a W-CDMA system were presented. In the dynamic IGM scheme, the resource-reservation module is used to dynamically reserve an interference margin for the use of potential high priority handoff calls by referencing the traffic condition and mobile users' traffic profile in neighboring cells. The mobility-aware weighted sum plays an important role in the resource estimation process. The effect of different mobility is thus taken into consideration. Under light as well as heavy traffic conditions, our proposed fixed and dynamic IGM schemes outperform the non-priority scheme in the overall objective function J. We considered a service model that includes mobile terminals' service rate, their different levels of priority, rate adaptivity as well as their mobility. Our resource reservation scheme provides a good estimate of the amount of resource needed to be reserved for potential higher-priority handoff calls. This gives better QoS in terms of the objective function while providing QoS guarantee to higher-priority calls.

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